Development of a Novel Technique for Hot Torsion Testing of Samples with Non-uniform Temperatures

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Introduction

Friction stir welding tool technology has advanced to the point that higher melting temperature materials, such as steels, nickel alloys, and titanium alloys, are proving to be joinable by the process. The microstructures developed during friction stir welding are the result of rapid heating, high strain and strain rates, and fast cooling. The deformation which occurs during joining makes quantifying the effects of the friction stir welding process difficult. A physical simulation technique has been developed which provides a means for quantitatively studying the effects of heating, straining, and cooling on the development of material microstructure.

Technical Approach

A Gleeble® 3800 with hot torsion capability was chosen for simulating friction stir welded microstructures. This system was chosen for its ability to accurately control temperature and strain. The torsion loading capability of the machine allows for the development of high strains at high rates.

Ingot iron and HSLA-65 were the materials used in the study. Ingot iron for its simple metallurgy and HSLA-65 because it has been the focus of studies on its weldability by the friction stir welding process. Microstructures from friction stir welds made in the study materials were used for comparison to the hot torsion samples.

Results/Discussion

Tests utilizing the standard hot torsion sample design did not achieve the cooling rates reported for friction stir welds. Cooling rate experiments ultimately led to an annular sample geometry used in conjunction with gas quench. The cooling rates achieved with this combination exceeded those measured in friction stir welds.

The rapid resistive heating prevented the formation of a uniform temperature across the gage section of the samples. This, in turn, caused a non-uniform distribution of strain when torque was applied. Samples with a line scribed across the gage section proved useful in quantifying the distribution of shear strain. In addition to the scribed line, multiple thermocouples on the sample provided data about the temperature gradient in the gage section. Combining the thermal data and strain distribution allowed the shear strain to be plotted as a function of temperature.

The data showed that in general the amount of shear strain increased as the temperature increased. At temperatures in the intercritical temperature region for both the ingot iron and the HSLA-65, the strain did not follow the trend observed at higher temperatures. When the center of the gage section was at temperatures in or just above the intercritical temperature region of the material when torque was applied, the shear strain increased with temperature to a maximum at a point in the intercritical temperature region and decreased with increasing temperature above that point.

Analysis of variance for the heating due to deformation was conducted on the data acquired from designed experiments using the annular torsion samples. Heating rate was shown to decrease as temperature increased, a trend opposite that observed for the shear strain.

Conclusions

The test developed is capable of quantitative measurement of shear strain in a hot torsion sample with non-uniform temperature distribution. The magnitude of local shear strain is determined by the flow stress of the material. Localized heating due to deformation is also related to flow stress. The difference in activation energy for ferrite and austenite, which affects the flow stress, causes increased heating and decreased deformation at temperatures close to the A_3 temperature.